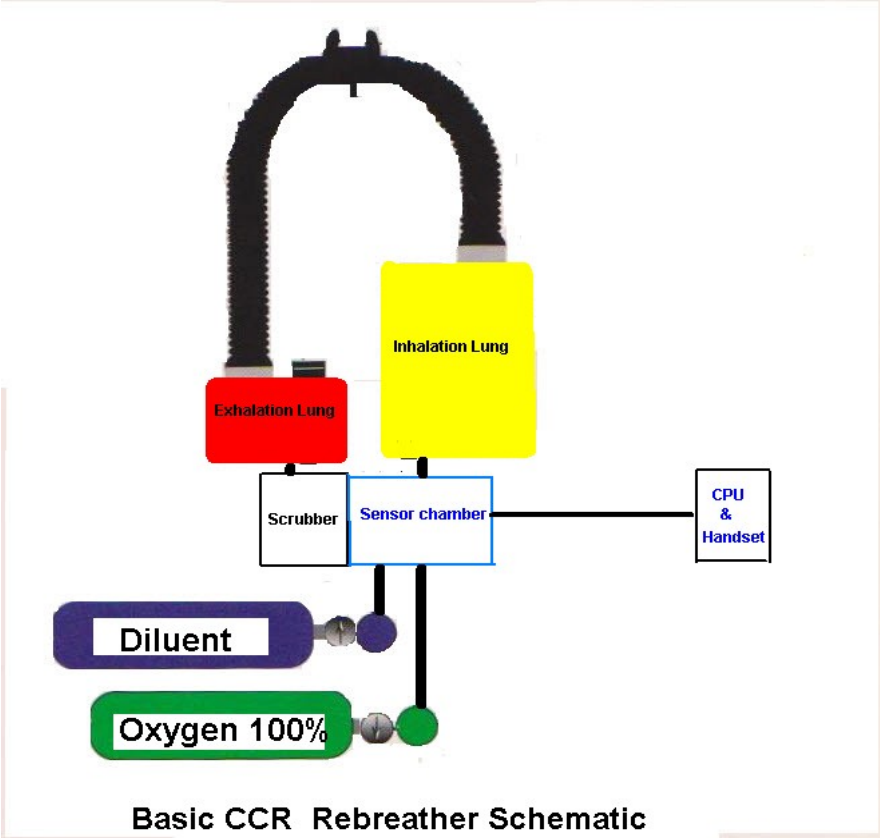
Solid State Sensors in Re-Breathers

Objective
To produce a sensor or combination of sensors that could be used to measure
End Tidal CO_2
Breath by breath CO_2 ,
CO_2 breakthrough
Oxygen content.

General theory of a re-breather



Basic CCR Rebreather Schematic

The actual location of various components will vary from manufacturer to manufacturer however the end result should be the same. The Diluent and Oxygen can be fed into the system at other points. This diagram is just one example. The objective is to re-cycle the oxygen by removing CO_2 and replacing the Oxygen used and converted into CO_2 with fresh Oxygen.
A Diluent gas is used to change the set point and to compensate the divers weight on descending. The diluent gas can also be Helium to increase the depth of the dive

Diluent gas usually air and with 100% Oxygen are fed into the sensor chamber and mixed . The CPU measures the PPO2 and mixes the gas until a fixed point is reached I.e. 0.7 or 1.3Bar. The 0.7 is used to travel down from the surface to about 20mtrs. The set point is then changed to 1.3Bar. Depending on rebreather software the set point may be continuously variable controlled via the CPU throughout the dive.

Solid State Sensors in Re-Breathers

The diver breathes from the inhalation lung through a one way valve and out of the mouthpiece via a one-way valve into the Exhalation lung. The diver absorbs about 4% Oxygen from the gas and replaces it with 4% CO2 but also he adds 100% RH (relative humidity) @ a temperature of 37°C

From the exhalation lung the gas is fed through a scrubber where the chemical reaction removes the 4% CO_2; The chemical reaction heats up the gas and as a by-product creates water. When the gas reaches the exhalation lung it is short of 4% Oxygen so the CPU adds Oxygen to replace it.

If the diver rises and reduces the water pressure the overall pressure in the system will rise so a pressure bleed-off valve is inserted into the exhalation lung.

If the diver stays at a fixed depth and has a constant work load, & metabolism the system will stabilise at the set-point with 100% humidity in the gas. This RH varies around the breathing the breathing circuit.
However when the diver exhales, the hot warm wet gas passes down a corrugated tube which is surrounded by water. If the temperature difference is high enough rain-out will occur. This is collected in the exhaust lung and can be expelled. The gas passes through the scrubber and collects water from it due to the chemical reaction. As the scrubber and the inhalation corrugated tube are surrounded by water rain-out can also occur. The net effect of this is that the mouthpiece sees a reduced temperature and a reduced RH.

Usually the CPU employs 3 sensors to monitor the gas mixture. The two nearest , electronically, are used as a control.
There are two effects to be remembered.
The diver is not a constant and his metabolism changes and he is not usually at a constant depth so the servo system is continuous. I.e. we cannot expect a constant 1.3 set point. The actual value in the mixing chamber will vary above and below 1.3 as the servo system tries to regulate. The actual mechanism is a solenoid which squirts Oxygen into the system. Diluent should not be normally used except during the time the diver is descending.

Basics of re-breather diving

A normal dive will last between 1hr and 4 hours. If two dives are carried out on the same day a gap of 2-4 hrs is recommended between dives.
Specialist divers may be under the water for up to 10 hrs. continuous.

Sensors must therefore be able to cope with both extremes.
Economically they should have a life of 1000 hrs minimum.

Current Standards EN14143
This standard stipulates that the control system must be within 0.1Bar of the set point at all times.

Current position of sensors
Work needs to continue to improve
Stability
Accuracy

Solid State Sensors in Re-Breathers

Linearity
Reproducibility
However the current sensors can be used in a programme to develop simple monitors whose complexity can be increased as the sensors improve.
There are five main applications of solid state sensors in re breathers. They can all be applied together or as stand alone applications

1. Project 1
   CO2 breakthrough
   Mounting a sensor on the outlet of the scrubber should allow the detection of minute levels of CO_2. The sensors are especially sensitive at ppm. The critical limit will be the stability and calibration. The current sensor appears to be applicable in this application.
   It is suggested we start with a traffic light system
   1- 4MB = Green
   5MB – 9 Bar = Orange
   10Mb = Red
2. Project 2
   Oxygen content
   EN14143 dictates that the gas inhaled by the diver should be within +/- 0.1 Bar of the set point .
   It should be possible to develop the current Oxygen sensor so that it can be calibrated in air 20.9% or 100% Oxygen and monitors accurately from 0.5Bar to 2 Bar Oxygen.
   This could be mounted on the scrubber as an independent 4th sensor
3. Project 3
   The end tidal CO_2 is the CO_2 content at the end of a breathing cycle. It can be displayed as a figure, a graph, or a combination. If input and output are measured the difference could possibly be used to eliminate movements on the baseline. If reliability and accuracy can be achieved three measurements can be made
   1. CO_2 on the inhalation ….. an indication of breakthrough. Need to check if can be measured at the mouthpiece and still reflect what is happening in the scrubber. The time delay may be too great.
   2. Highest value on exhalation would be etCO_2
   3. The baseline on exhalation would be CO_2 retention
4. Project 4
   Combined O_2 and CO_2 sensor would display
   1. Oxygen delivered and variations from set point
   2. etCO_2
   3. CO_2 retention
   4. CO_2 breakthrough
5. Project 5
   By combining a flow sensor to the above Divers workload could be derived.

Oxygen control
The existing system of using three galvanic sensors has been proved over 15 years.
Although the solid state sensor solution is appealing long-term stability and reliability need to be proved.